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MOBILE GAME FOR MOTOR AND COGNITIVE ASSESSMENT

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ABSTRACT

In the present day almost everyone has a powerful computer in their pocket, a smartphone. These new affordable devices can replace some traditional ways of assessing health. In this project we focused on assessing motoric and cognitive properties using a mobile application that we developed along the way.

We looked into research related to the subjects of our project, such as reaction time, memory measuring methods, input accuracy, and serious games. Then, we looked at some potential use cases for this type of application. Before we started developing the application, each researcher made a small demo application to gain some experience with Android development.

The mobile application that we designed was developed for the Android platform. It has two games, one for measuring memory, and the other for measuring input accuracy and reaction time. After the application was done, we tested it with our friends and family members to gather data. The tests were conducted between two age groups, one consisted of testees from age 20 to 25, while the other had testees from age 50 to 65. The results were then analyzed by using Mann-Whitney U test to assess the differences between the age groups. We also took notes of our observations during the tests and asked the testees for feedback on the test procedure and the games after the test.

The younger age group got significantly better results as expected. However, the results of the older age group do not properly reflect their abilities, as the older age group is not as used to playing games or using a smartphone as the younger group, and because the games ended up being quite complex. Some of the testees from the older age group kept playing the games after the testing was done and got up to ten times higher scores than in the testing phase.

We hope that at some stage the application could potentially be used to assess motor dysfunctionalities and cognitive impairment in elderlies and disabled people.

Keywords: Serious game, medical application, mobile game, data assessment, elderly people.

Vaara N., Peltomaa S., Holappa J. (2020) Mobiilipeli Motoristen ja Kognitiivisten Ominaisuuksien Arviointiin. Oulun yliopisto, Tietotekniikan tutkinto-ohjelma, 46 s.

TIIVISTELMÄ

Tänä päivänä melkein jokaiselta löytyy taskustaan tehokas tietokone, eli älypuhelin. Näiden uusien kohtuuhintaisten laitteiden avulla voidaan mahdollisesti korvata vanhoja tapoja arvioida terveyttä. Tässä projektissa me keskityimme mittaamaan motorisia ja kognitiivisia ominaisuuksia mobiilisovelluksen avulla, jonka kehitimme projektin aikana.

Tarkastelimme aiemmin suorettuja tutkimuksia, jotka koskevat meidän projektimme eri osa-alueita, kuten reaktioaikaa, muistin mittausta, syötetarkkuutta ja hyötypelejä. Lisäksi tarkastelimme joitain mahdollisia käyttökohteita tämän tyylisille sovelluksille. Ennen sovelluskehityksen aloittamista jokainen tutkijoista teki pienen demo sovelluksen saadakseen hieman kokemusta Android kehityksestä.

Mobiilisovellus, jonka suunnittelimme kehitettiin Android alustalle. Se sisältää kaksi peliä, joista toinen on muistin mittaamiseen, ja toinen syötetarkkuuden sekä reaktioajan mittaamiseen. Sovelluksen valmistuttua testasimme sitä ystävillämme ja perheen jäsenillämme kerätäksemme dataa. Testit suoritettiin kahden ikäryhmän välillä, ensimmäisen ryhmän testaajat olivat 20-25 vuotiaita ja toisen ryhmän testaajat olivat 50-65 vuotiaita. Analysoimme tämän jälkeen tuloksia Mann-Whitney U testillä arvioidaksemme eroja ikäryhmien välillä. Otimme myös ylös havaintoja testauksen aikana ja kysyimme testaajilta palautetta testiproseduurista sekä peleistä testin jälkeen.

Nuorempi ikäryhmä sai huomattavasti parempia tuloksia. Kuitenkin, vanhemman ikäryhmän tulokset eivät täysin vastaa heidän kykyjään sillä vanhempi ikäryhmä ei ole yhtä tottunut pelaamaan pelejä tai käyttämään älypuhelinta kuin nuorempi ikäryhmä ja koska pelit olivat lopulta melko monimutkaisia. Osa vanhemman ikäryhmän testaajista jatkoivat pelien pelaamista testauksen jälkeen ja saivat jopa kymmennen kertaa suurempia pistemääriä kuin testauksen aikana.

Toivomme, että tätä sovellusta voidaan joskus käyttää motoristen toimintahäiriöiden ja kognitiivisten rajoitteiden arviointiin vanhuksilla ja motorisesti tai kognitiivisesti vajaakuntoisilla henkilöillä.

Avainsanat: Hyötypeli, lääketieteellinen sovellus, mobiilipeli, datan arviointi, vanhukset.

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FOREWORD

We would like to thank Elina Kuosmanen, Valerii Kan, Matti Pouke and Aku Visuri for their assistance during this project. We would also like to thank our friends and family members for participating in the evaluation of our application.

Oulu, May 27th, 2020

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LIST OF ABBREVIATIONS AND SYMBOLS

IP	Index of Performance
ID	Index of Difficulty
MT	Movement Time
UI	User Interface
OS	Operating System
RT	Reaction Time
PD	Parkinson’s Disease
AD	Alzheimer’s Disease
CP	Cerebral Palsy
MS	Multiple Sclerosis
P	Percentage
O	Number of Correctly Recognized Objects
W	Number of Incorrectly Recognized Objects
K	Number of Alternatives Given for Recognition
N	Number of Items Presented for Learning
L	Number of Learning Trials
R	Number of Relearning Trials
ρ	ρ-value
U	Statistic
z	z-value

1. INTRODUCTION

As the mobile industry has grown by leaps and bounds during this decade, it has created many new opportunities for business, healthcare and many other fields. This has been made possible by smartphones and their ease of use, low requirements for programming apps and low costs. In this project we will focus on the healthcare side and the goal is to program an app that is mainly meant for older people or people with motor dysfunctionalities or cognitive impairments and its purpose is to measure reaction time, memory and input accuracy for starters.

People with cognitive problems can have trouble with memory, thinking, language, observation and attention. Cognitive problems are usually observed in old people as they are more vulnerable to them and the effects are more noticeable and now that the older population is increasing rapidly in many countries and especially in the wealthier countries, the demand for applications or technology to maintain and assess cognitive health should be increasing [1, 2].

Nowadays in many developed countries birthrates have fallen and population growth is slowing down or even negative and at the same time our advanced healthcare and high standard of living enables us to live longer than ever before. Because of this development there is a shortage for nurses and workers in retirement homes that is only going to get worse. Technology cannot solve this for us because it is a people problem but we think it definitely can help mend the situation.

Many studies have shown that video games have cognitive benefits which include preventing or delaying the decline of cognitive functions but also improving reaction time, cognitive functioning, visuomotor coordination, intelligence, attention and concentration, self-esteem and quality of life. Now of course video games are not the only solution nor are they for everyone but they are certainly worth exploring and researching. We found many brilliant studies conducted in Finland mainly by Merilampi, S. , Sirkka, A. , Koivisto, A. and others about designing serious and cognitive games for older adults and implementing them into care services. The studies found improved reaction times, attention, activation level and overall well-being [3, 4]. We mentioned earlier that games could help in shortage of nurses and here it actually did as the participants reported the games as interesting, exciting and entertaining. The games could effectively be used as a proactive service for elderlies to maintain their cognitive health by themselves and making them less dependent on professionals and thus freeing nurses to other care activities [3].

Another a bit older experiment in Japan featuring an electronic-mechanical also reported similar success in many same aspects. Although there can be some cultural differences, the study showed that elderlies rarely play alone and having a competitive element like displaying scores and being able to watch others play lead to increased enjoyment and also that way the elderlies would not only entertain and help themselves but others as well [5].

In this project we will be developing a mobile application that includes two games which are designed to measure memory, reaction time and input accuracy while also being fun to play. Our goal is to assess the differences in motor and cognitive performance between age groups. To achieve this, we will gather data with the application from two different age groups, analyze the data and discuss the results and findings.

In chapter 2 we will introduce the background research and related work. After that in chapter 3 we will discuss the design and implementation of our mobile game. Evaluation of the project will be in chapter 4 and chapter 5 is for our discussions. Chapter 6 will have our final conclusions, chapter 7 will have our contributions for the project and chapter 8 is for the references used in this project.

2. BACKGROUND RESEARCH AND RELATED WORK

In this section we will introduce our work regarding the background research and related work. In the first section of this chapter we will cover the relevant measurements and concepts related to our application, these are Fitts' Law, reaction time, Hick's Law, methods for measuring memory and input accuracy. In the second section we will explain the term serious game, give some reasoning why and how the term is used here and discuss a little about why they have been rising in quantity in the recent years. After that we discuss how video games in general could help older adults with cognitive and physical health problems. Next we will discuss the potential use cases where the application could be found helpful which are Parkinson's disease, Mild Cognitive Impairment, Cerebral Palsy and Multiple Sclerosis. Lastly we go over the technology and software that we are going to use in the development of our application and also give 3 demonstrations about using them.

2.1. Measurements

2.1.1. Fitts' Law

Fitts' law is a model for predicting human movement and in this case the movement can be compared to transmission of information. Movements are given indices of difficulty and to perform these movements the human motor system transmits "bits of information" which are the unit for difficulty [6].

Fitts' law states that the time required to move a pointer like a cursor to a target or touch a specific area on a screen is a function of the distance to the target divided by the width of the target. This law has been found especially useful in human-computer interaction and designing user interfaces [7].

Fitts wanted to demonstrate the information capacity of the human motor system. He called this capacity the index of performance (IP). This IP is equivalent to the channel capacity (C) in Shannon's theorem. IP can be calculated by dividing the difficulty of a task (ID) by the time it takes to move (MT) to complete the task [6].

$$IP = ID/MT \tag{1}$$

Fitts stated that electronic signals are equivalent to movement distances or amplitudes (A) and that noise is the same as tolerance or width (W) of the target area. The following equation can be used to calculate the index of difficulty (ID) and is loosely based on the Shannon's logarithmic expression [6].

$$ID = log2(2A/W) \tag{2}$$

The unit of task difficulty is bits because 2 was chosen as the base for the logarithm. A variation of equation 1 can be used to conveniently calculate MT by placing it on the left [6].

$$MT = ID/IP \tag{3}$$

All of this can be tested by designing a series of movement tasks where subjects move to targets of width W at a distance A as quickly and accurately as they can. The test should have different difficulties for each of W and A. The IP can be calculated directly using Equation 1 or it can be calculated with the following regression line equation where a and b are regression coefficients:

$$MT = a + bID \tag{4}$$

The reciprocal of the slope coefficient (1/b) corresponds to IP in Equation 3. A common form of Fitts' law is an expanded form of equation 4 [6].

$$MT = a + blog2(2A/W) \tag{5}$$

Fitts added the 2 in the logarithm to ensure that the ID was greater than zero for the conditions used in his experiments. This increases ID by 1 bit for each task condition [6].

2.1.2. Reaction Time

In reaction time assessment we need to take a lot of things into account, especially since our goal is assessment of elderly people or people with motor dysfunctionalities and cognitive impairments. One type of reaction time (RT) is called simple reaction time, which is the time interval between the onset of the stimulus, and the initiation of the response under the condition that the person playing our game is responding as rapidly as possible. After the onset of the stimulus, during which the receptor process is initiated to a maximum. This is followed by central transmission of the sensory impulses to the motor fibers. Lastly, there is a time delay involved in the contraction of the muscles and the beginning of the movement of the responding member. Anything affecting these processes will obviously also affect our RT [8].

Another type of RT is choice reaction time, which is defined as the time elapsing between the onset of the stimulus and the initiation of the response as well, but there are also the alternative stimulus and responses [3], for example if we have to press a specific button depending on the color shown on the screen. There are a lot of different factors we need to consider, for example motor factors, and loss of sleep [8], and since we are developing for Android touch screen devices, there will be some latency before the device registers and handles our input.

Most multitouch systems today use mutual capacitance sensors that measure the capacitive coupling from each row to each column on a 5-6mm grid, and the touch sensors are typically run at a 60Hz scan rate, which results in about each grid point being scanned every 17ms. There is an arduous path between the sensor and the display that involves communications, the operating system, UI toolkits, the application layer, and of course, the graphics layer. In our case the OS is Android, which is not a real time operating system. Because of this there is no guarantee that a response will happen within a certain time period, for example, if the processor is heavily loaded, we might have dramatic increase in the time before our screen touch event is processed. Which of course adds up to the total device input delay. The delay before our application handles our touch event from the moment our finger touched the touch screen just keeps getting higher and higher. A study using high-speed cameras tested a wide variety of iOS, Android, Windows, and Windows Phone devices doing basic OS navigation tasks found out, that the average input latency ranges around 50-200ms in the current commercial devices [9].

Sleep deprivation is also a huge factor in RT assessment. Based on a study done for eighteen college student athletes consisting of a two-choice reaction task with the first measurement after 3-day period of around 9-hour sleep per night, and the second measurement after one night of sleep deprivation, the results were significant. It was revealed that the mean choice RT of subjects exposed to sleep deprivation was significantly slower than the baseline [10].

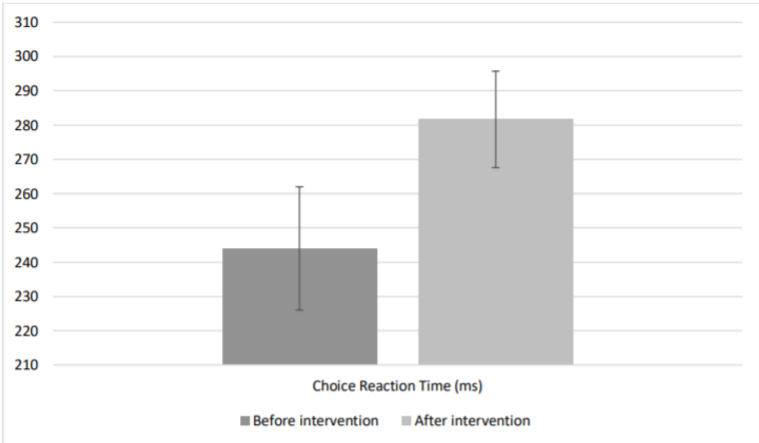

Figure 1. Visual representation of the study based on the effect of sleep deprivation on RT.

The difference in RT between genders was found to be notable in an investigation by Elliot and Louttit [11]. Based on the results the braking reaction of men is significantly quicker than women in automobiles. Seashore and Seashore [12] found out that men are significantly faster in various muscular responses, especially after practice.

The assessee should also be tested if he is under the effects of drugs or intoxicated. It was reported that for example morphine has the effect of first shortening and then lengthening the reaction time, except when taken in large doses, in which case the reaction time only gets lengthened [8].

Bellis [13] conducted a study based on ages ranging from ages 4 to 60 years, it was noted that both visual and auditory reaction times are at it is best until around age 30, after which the latencies started to grow longer. Surprisingly the RT is still faster at age 60 than it is at age 10. Miles [14] used three different kind of responses to observe the RT based on age on 100 adults aged 25 – 87 and found low (0.25 to 0.55) but significant positive correlations between age and RT [8].

Another thing to note is that since our target audience might have motor dysfunctionalities, the input might not be accurate. One solution to this could be for example if we have multiple buttons which should be pressed based on what’s on the screen, and we take the closest button based on the received input, and if it’s the correct button, we add the RT to our assessment.

2.1.3. Hick's Law

Hick's law states that response times increase in proportion to the logarithm of the number of potential stimulus-response alternatives [15]. It is named after William Edmund and Ray Hyman who set out to examine the relationship between the number of stimuli present and an individual's RT to any give stimulus, which obviously results in longer time if there is a big number of stimuli present [16].

$$RT = a + blog2(n) \tag{6}$$

Where "RT" is the reaction time, "n" is the number of stimuli, and "a" and "b" are the measurable constants that depend on our task and conditions. As we can see, the concept of Hick's law is quite simple, the smaller the number of stimuli is, the faster decision-making process we get with some exceptions being, that a user might have already decided before seeing the stimuli [16].

Hick's law implementation is quite common in software design in today's world. A design principle known as "K.I.S.S" ("Keep It Short And Simple") became popular in the 1960s for its effectiveness. It is echoing Hick's Law by stating that simplicity is the key for a system to work in the best way. Complex processes can be rationalized by using Hick's Law, for example having only specific parts of a process show up one at a time instead of having all parts show at once. This is so that the users don't get overwhelmed with the information [16].

2.1.4. Methods for Measuring Memory

Sometimes we might feel that we can't remember all the things that we had learned earlier. That is when we come to realize the imperfect nature of our memories and our cognitive abilities to store, learn and retrieve information, making it a challenge to measure it. Ebbinghaus (1900) can be credited with this first systematic assessment of memory [17].

Memory is an internal process that cannot be observed, however, the methods of measuring memory have since evolved and with observable performance from various tasks and tests we can deduce the amount of information retained in the memory. The methods for measuring include direct methods which are recall, recognition, relearning and reconstruction. The indirect methods focus on measuring the amount of information carried from previous task to the next [17].

Recall is the most widely used direct method of measuring memory. It is a simple and passive method where subjects reproduce learned materials such as a text as best as they can, word for word after a certain time period. For example, remembering the words for a song even if the person does not remember when or where he heard it. Many factors can affect recalling for example, how short, interesting or meaningful the material is and the amount of rehearsals. Recalling can be divided to free recall and serial recall. In free recall the pieces of information are summoned without any specific order and in serial recall the information is recalled in the order it was learned [17].

Recognition is an active process where the subject identifies different elements for example, seeing a familiar picture which acts as a stimulus for remembering where the person saw it and the context behind it. Recall does not have this stimulus. Recognition combines information from learned and unlearned materials to identify the object. Percentage of recognition can be calculated with the following formula:

$$P = O - W/K - 1 * 100/N \tag{7}$$

Where P is the percentage, O is the total number of correctly recognized objects, W is the total number of incorrectly recognized objects, K is the total number of alternatives given for recognition (old + new) and N is the number of items originally presented for learning [17].

Recognition is easier than recall because the object is presented in a mixed form with new elements and depending on the subject's motives, attitude, prejudice and values, the sensitiveness is greater. Recognition also becomes more difficult the more similar the original and new material are, causing more errors [17].

Relearning was introduced by Ebbinghaus (1885) for measuring the quantitative aspect of memory and is the most sensitive measure and supposedly the most efficient way of remembering information [17, 18]. This method is also known as "saving" and the measuring is done by giving the subject a list of materials to learn and after a time period he is given the same list to relearn. The number of trials and time taken are recorded after which the percentage of saving can be calculated with the following formula:

$$P = L - R/L * 100 \tag{8}$$

Here the P is again percentage of saving, L is total number of learning trials and R is total number of relearning trials. The final direct method of measuring memory is reconstruction where some object is presented to the subject and then it is broken up into pieces which the subject has to reconstruct back to its original form [17].

2.1.5. Input Accuracy

With mobile devices input accuracy is an important aspect to take into consideration since with high input accuracy the users can finish the tasks, they are trying to accomplish, quicker and with fewer errors [19]. Fitts' Law is related to measuring input accuracy since it is a law that helps to predict human movement. We discussed Fitts' Law thoroughly earlier in section 2.1.1.

There are multiple things that effect the input accuracy. Biases, such as touching repeatedly below the target or left of the target when the target is on either side of the device, have been found by [20] when studying touchscreen keyboards. These biases can be used to adjust the location of the actual touches to match better with places were the users are trying to touch. Also, the size of the targets needs to be considered carefully to make touching them easy. As mentioned in [21] one common reason for users to make unintentional mistakes is the smaller size of the user interface on smartphones. Another reason for mistakes that they mention in

[21] is that the touchscreen buttons do not have physical boundaries hence the users do not get tactile feedback of the touch. Then again, tactile feedback measures such as vibration-on-touch have been implemented and they can be found on most of the newer smartphones. All these things mentioned above need to be taken into consideration when considering input accuracy while implementing something on touchscreen devices.

2.2. Serious Games

The term serious game seems to have a little inconsistent meaning depending on who is using it and in what context they are using it. Just to show a few examples of some definitions; some interpret the term the way that it means a game that has no fun element [22], some interpret it the way put by the authors of [23] "… serious games are IT applications that combine aspects of tutoring, teaching, training, communications and information, with an entertainment element derived from video games." and some just call the term as only a marketing technique [24]. In [25] many different definitions are showed, and in [25] they have come to their own conclusion of the definition being "… we define serious games as an application with three components: experience, entertainment, and multimedia…". But seemingly most often serious game is defined as a game that has some other important purposes than just entertainment [26, 27, 23]. That is also how we are using the term and that is why our game can be called a serious game since it will have the purpose of gathering the data of the game played and hence it could be used as an assessment tool.

As said in the definition used by [23] serious games can have multiple purposes such as teaching and training. The reason why large numbers of serious games have recently come to the market of health related inventions is mostly because in the following years there will be more older adults than ever before and with that comes more aging related health concerns so there will be high demand for low-cost and easily accessible ways to treat the effects of aging [28, 3]. In many cases, repetitive tasks are required to treat the patients, but boredom affects negatively to the patient's willingness to continue the treatment. The use of tailored games to replace these tasks has shown good results so far [29].

2.3. Older Adults and Video Games

The effects of older adults playing video games has been studied and the found positive effects vary from physical to psychological to cognitive [30, 3]. Cognitive skills include skills such as memory, attention and concentration, reasoning and problem solving, judgement, etc. [31]. Then again, memory disorders can be seen as physical, psychological and cognitive challenges [3], so not only is memory a cognitive skill but it effects also physical and psychological health.

It is shown that age related cognitive decline can be decreased or slowed down by having cognitive stimulation [31]. Then again, the way the stimulation is used, such as quantity, duration and intensity, effects the results [31].

One study found called Effects of Interactive Physical-Activity Video-Game Training on Physical and Cognitive Function in Older Adults [30] focused on the benefits related to playing exergames, games that inquire significant physical exercise by using physical input devices. Exergames played in the study combined physical and cognitive exercises and were played by the training group for 2 hour per week for 14 weeks, referred as training weeks, while the control group did not play any exergames. The results were measured by using various test that were conducted before and after the training weeks and were categorized in four different groups: Physical Measures, Executive Function, Visuospatial and Processing Speed. In the study it was found that playing exergames can provide physical and cognitive benefits for older adults. That is backed by the fact that there was noticeable improvement seen on all the 4 groups of tests.

Another study found on the subject of older adults and the effects of gaming was Cognitive mobile games for memory impaired older adults [3]. This study used two different games that were played using a touch screen device for three-month test period. The participants average age was 90 years and they were all residents of a nursing home. First game combined physical movement and cognitive stimuli. The game was called Cat vs Mouse and it was played by tilting the device in the direction the player wanted the mouse (i.e. the character they played) to go. The goal was for the mouse to reach as many cheese chunks as it could before it was caught by a cat or the time run out. Level of difficulty was added during the game by increasing the amount and the speed of the cats. The second game was based on a Trail Making Test that is used for cognitive impairment assessment and detection. The Trail Making Test has two parts, but only the first part is related to the game and thus referred to here. In the first part, which is done by using a pen and a paper, the testee is going to connect numbered circles from 1 to 25 in numerical order as fast as possible by drawing a line between them without lifting the pen. In the game version connecting is done by only tapping the numbers. Also, the original Trail Making Test was used as a comparison of the results of the gamified version. It was found in the study that most of the testees personal game scores improved during the test period and that playing the games was activating and entertaining for the testees, their attention skills improved, and the gaming effected positively on their overall well-being.

Most of the participants (i.e. residents of the nursing home) found playing games as an interesting thing to do which activated them and gave them something to do even when the care staff were not around. In general games and video games are often found as motivating thing to do [30] and that combined with the serious aspect of the serious games, it can make serious games a good tool for self-managed activity and rehabilitation for older adults [3].

2.4. Potential Use Cases

In this section we will cover some potential use cases for the game application. All of the following diseases involve some sort of motor or cognitive impairment which can be assessed with the application. For example the symptoms of Parkinson's disease include shaking and tremor, the application could be used to measure the severity of the symptoms through input accuracy and reaction time. Memory measuring can be used for mild cognitive impairment.

After testing the game with multiple diseases and reviewing data, there is a chance to notice correlations. For example if the memory results of the PD patient become similar to the MCI patient or worse then the PD patient is likely at an advanced stage of the disease where cognitive problems and dementia become common.

2.4.1. Parkinson's Disease

Parkinson's disease (PD) is a progressive disease with a mean age at onset of 55. The incidence increases clearly with age from 20/100,000 overall to 120/100,000 at age 70. In 95 percent of cases there is no genetic linkage, but in the remaining cases the disease is inherited. After 5-10 years of PD, most of the patients suffer a remarkable amount of motor disability, even with symptomatic medications. The cause of sporadic PD is unknown with the effect of environmental toxins and genetic factors being uncertain. Clinically, any disease that includes direct striatal damage or striatal dopamine deficiency may lead to "parkinsonism", a syndrome, which can be characterized by, for example, tremor at rest [32].

Symptoms of PD include tremor, which usually occurs at rest and decreases with voluntary movement, so daily activities can usually be done without impairment to daily living. Stiffness of patient's limbs, hypokinesia, which means reduction in movement amplitude. Bradykinesia affects everyday tasks such as dressing or eating. Stooped posture developed by Parkinson's Disease may cause the loss of normal postural reflexes, which may lead to falls and possibly confinement to a wheelchair. The inability to begin a voluntary movement, such as walking, which is called freezing is a frequent symptom. This might cause, for example that the patient remains in it position when he tries to begin walking. Abnormalities of affect and cognition are also frequent symptoms of Parkinson's Disease. This results in patients being passive or withdrawn with lack of initiative, which may result in the patient sitting quietly until encouraged to participate, for example in a discussion. Responses to questions are delayed and cognitive processes are slower. Dementia has been found significantly more frequent in Parkinson's Disease, especially in older patients [32].

Studies of toxic PD models and the functions of genes implicated in inherited forms of PD two major hypotheses regarding the pathogenesis of the disease, one of them being that misfolding and aggregation of proteins are instrumental in the death of SNpc dopaminergic neurons. The other hypothesis proposes that mitochondrial dysfunction and the consequent oxidative stress, including toxic oxidized dopamine species is the main source. [32].

PD causes abnormal deposition of protein in brain tissue, however it is also a feature of several age-related neurodegenerative diseases. The location and composition of protein aggretates differ from disease to disease, which suggests that protein deposition or some related event is toxic to neurons [32].

As noted earlier, tremor caused by PD decreases with voluntary movement. The mobile game could help with both assessment of the patient's PD's severity, and reducing the tremor in hands with the gameplay.

2.4.2. Mild Cognitive Impairment

Memory problems are especially significant because they require support from health and social services and intervention. Alzheimer's disease is a common and deadly disease mainly diagnosed in older people. Before developing AD however, patients can be diagnosed with mild cognitive impairment which is considered to be a stage between normal aging and AD. Usually these symptoms come normally with age but if they get worse then they can be diagnosed. Approximately 15 to 20 percent of people aged 65 or older have MCI and therefore their cognitive health has declined or is declining faster than normally and they have an increased risk of developing Alzheimer's or another dementia [1, 2].

When a person develops MCI, it is often a result of many different causes and while these causes are still unknown, people with MCI have developed same kind of brain changes which include Abnormal clumps of beta-amyloid protein, Lewy bodies and small strokes or reduced blood flow through brain blood vessels. Currently there are no drugs or other treatments for MCI that approved by Food and Drug Administration (FDA) while the demand is high and increasing [1, 2].

2.4.3. Cerebral Palsy

Cerebral palsy, often referred as CP, is a non-progressive disorder occurring in foetal brain development or in early childhood, usually in the first 12 to 18 months of life [33, 34]. Typically, CP is shown as delay in attaining motor milestones or findings of asymmetric motor functions or abnormalities of muscle tone [34]. Cerebral palsy can be divided in 4 categories: spastic, dyskinetic, ataxic and mixed [34]. Spastic is the most common type and the affected area of brain is the cortex. Characteristics of the spastic type are deep tendon reflexes, hypertonia, flexion and sometimes contractures [35]. Dyskinetic type is characterized by involuntary movements of chorea, athetosis and dystonia. Some of the involuntary movements can decrease when the person is relaxed or sleeping or increase when the person is stressed or anxious [34]. Ataxic type is characterized by a loss of coordination, equilibrium and kinesthetic sense [35]. In the mixed type the person has symptoms of more than one of the other categories. Most common combination in the mixed type is to have symptoms of spastic and dyskinetic types [35].

In [36] the effects, for individuals with cerebral palsy, of playing virtual game on a mobile phone were studied. In the study both the experimental group, whose members have CP, and control group, whose members do not have CP, played a maze game called Marble Maze Classic in which they were instructed to find the path from start to finish as quickly as possible. Both groups were given the same amount of tries in the game. It was found that only the experimental group members significantly improved their results in the game when comparing the first and last attempts. It was concluded that the type of game used in the experience could offer possibilities for rehabilitation use.

2.4.4. Multiple Sclerosis

Multiple sclerosis (MS) is a disease of the central nervous system characterized by multicentric inflammation and destruction of myelin, which is involved in transmitting nerve impulses along nerve fibers. The name originates from the disease itself, because it causes lensions in large areas of the nervous system. Multiple genetic loci and environmental factors contribute to the suspectibility to the disease, however the primary cause of MS is unknown. The first symptoms of MS are often associated with breakdown of the blood-brain barrier. The disease is associated with a wide range of sensorymotor, congitive, visual and nerological disorders. Eventually MS results in permanent nerologic disability. [37, 38].

Compared to health subjects, explicit learning was significantly reduced in MS patients. In a study, MS patients' were tested with tests that are influenced by motor impairment. In these tests the MS patients had slower reaction time. The impairment observed in explicit learning is caused by slow information processing and impaired active memory capacity, which is troubled by higher demand. [38].

Even in the early stages of the disease the most well-known feature of MS is cognitive impairment. Areas that are affected the most include sustained attention, verbal memory and information processing speed. Patients with severe neurological disorder have non-specific learning destructed, while patients with milder disorders usually have it more preserved [38].

2.5. Technological Overview and Demos

At first we considered using Godot game engine for our application, but after discussing with our technical assistants they suggested using Android software development kit instead. After reviewing both options, we decided to abandon the idea of using a game engine.

We decided to use Android Studio as our integrated development environment, because it seemed like very user friendly and simple environment.

In the next three subsections we will introduce the demos we made in order to get familiar with the Android Studio environment.

2.5.1. Demo 1

First demo shows a simple two-paged design. The main function here is to alternate between the two pages. When the application is first opened, Activity 1 will open, as shown in figure 2 on the left. When the button that says Open Activity 2 is pressed, it will go to the Activity 2 page, shown in figure 2 on the right. By pressing the button that says Open Activity 1 we can go back to Activity 1. Also the default background color and font sizes were changed.

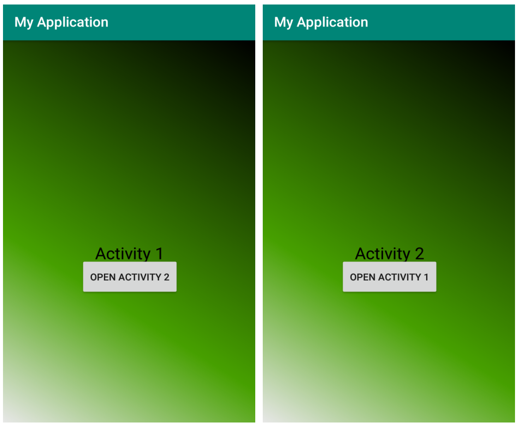

Figure 2. Activity page 1 and 2.

2.5.2. Demo 2

The second demo demonstrates how to draw a rectangle, and how to change color without relying on event dispatcher. The solution for this is calling invalidate after the initial View.onDraw call which invokes another View.onDraw for the next frame, and in the View.onDraw override we can then have our logic for changing the color. The View.onDraw function is usually called only a few times when the application is started or when using built-in widgets, since those have invalidate call built in.

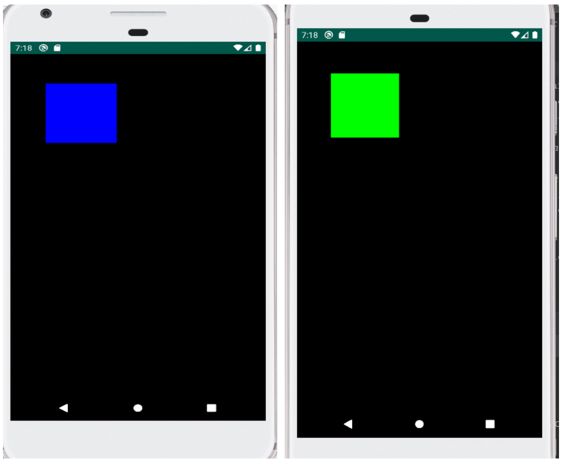

Figure 3. Drawing square and changing color.

2.5.3. Demo 3

The final demo features a simple drag and drop function. There are 3 different TextView boxes called Text 1, Text 2 and Text 3 which you can drag and drop to the target TextView box. The target recognizes when and which text has been dragged over it, dragged away from it or when it is dropped on it. Before it started dragging, the user had hold text for 500ms which is hard coded into the OnLongClickListener but after replacing it with OnTouchListener, the dragging now starts instantly.

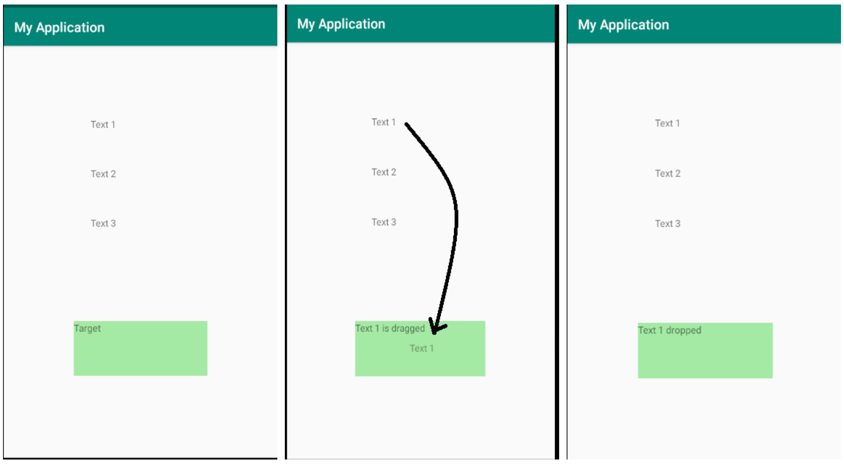

Figure 4. Drag and drop.

3. DESIGN AND IMPLEMENTATION

3.1. Design Ideas

We had our very first brainstorming session before we had begun doing our background research of the related work. At this session we tossed some ideas around and sketched some of them on a whiteboard, but we did not document them and did not come back to them again. Then again, some of them did influence the design ideas that we sketched out and out of which we chose the ones to implement, which are discussed later in this section. In this section some of those early ideas will be briefly introduced.

One of the early ideas was a game in which a set of numbers would pop up on the screen and the aim would be to choose the requested number by tapping it as quickly as possible. The requested number would appear on the top of the screen and the same number should be found in the set given earlier. Another version of this game included finding either the smallest or the largest number. This was thought as a possible reaction time measuring game.

The second idea was very similar to the first one in which a set of numbers would appear on the screen and after that there would appear a requested number which was this time a sum of some of the numbers on screen. The aim would be to touch the numbers which make the sum. This idea was quickly abandoned since it did not feel like something that would be enjoyable to play and would be only testing the mental calculation skills of the user.

The third idea was a game in which a set of colored shapes appear on the screen and in the middle of the screen there would be a hole which has a certain shape where you would have to drag and drop the shapes that correspond to the hole as quickly as possible while leaving the other shapes where they are. It was a decent idea and needed more refining.

We decided that the application would include 2 games: a memory game and a reaction game. The player can choose which game they want to play on the menu. After we were done with the background research and related work section, we agreed to find or come up with ideas and designs for a memory game and a reaction game for the next team meeting and present them there. At the meeting we then rounded up the ideas and designs to discuss and draw some sketches of them and finally decide what we were going to implement.

3.1.1. Memory Game Ideas

We figured out 3 designs for the memory game. The sketches for these can be found in Figure 5. First we discussed about a simple word memorizing game where the player is shown a bunch of words which disappear after a little while. The player was then shown the words again among other decoy words and you had to touch the words that were shown on the previous screen. We also considered typing the words. As the game goes on, you would have to memorize more words and thus becomes more difficult. We thought it was a pretty good idea that got the job done but it was fairly boring.

The next idea is about a simple trail memorizing game where a path of squares is generated on a grid one square at a time and when the path is complete, it vanishes.

The player then has to either touch or swipe the squares in order to recreate the correct path in order. The player is awarded points for remembering each square and bonus points based on time after completing the path, then another path is generated that is one square longer. If the player could not remember the whole path, the player loses the game. We deemed this idea more interesting and although it is not also completely original or new, we figured the gameplay would be fun.

Last, and most quickly abandoned, idea was a piano key inspired game in which you would hear a melody and see the keys been pressed and after the melody stops you should repeat it yourself by tapping the keys. Problems with this idea that rose immediately where such as how could we make those melodies and, moreover, how to make the melodies so that they would also be pleasant to listen to. So this idea was not very carefully considered while choosing the memory game that will be implemented.

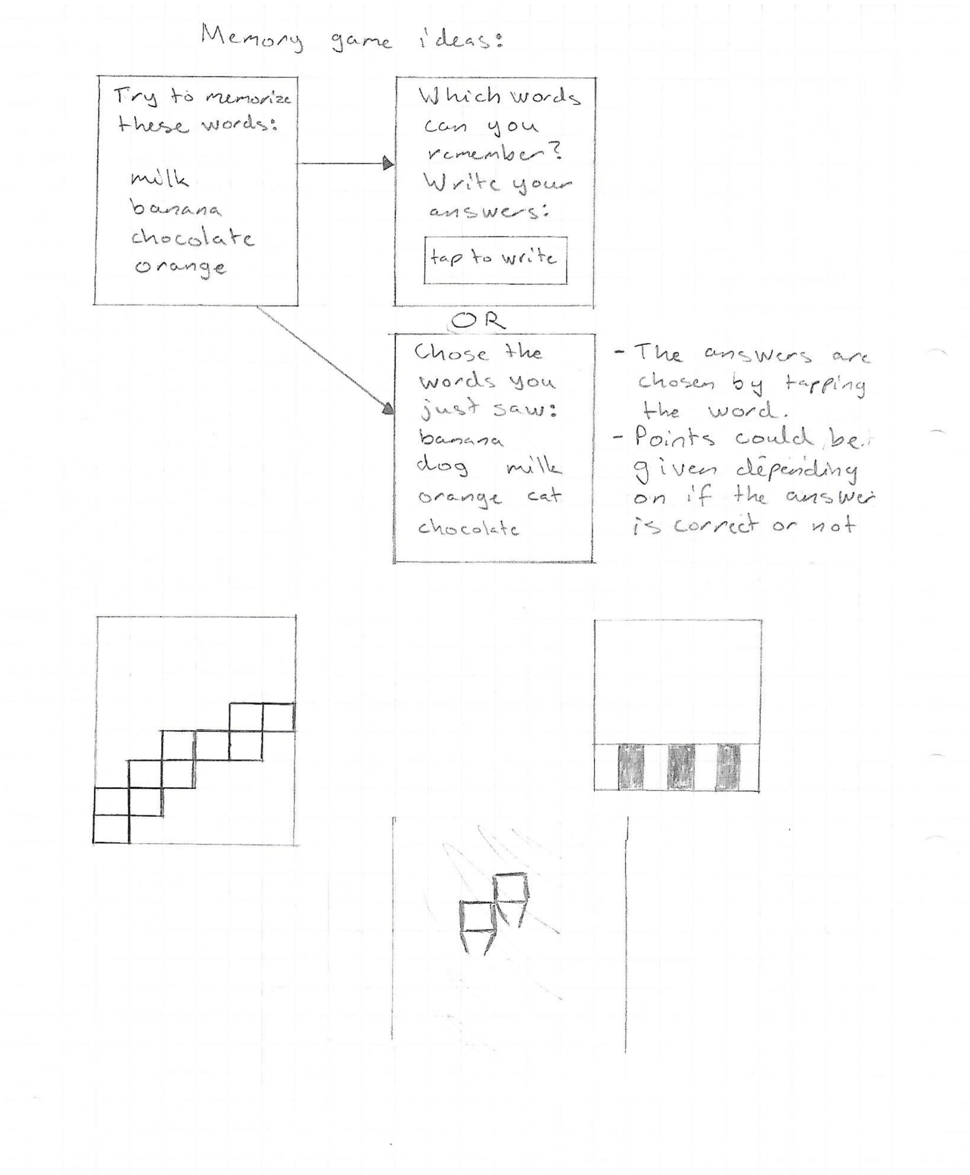

Figure 5. Memory game sketches.

3.1.2. Reaction Game Ideas

For the reaction game we came up with 4 different ideas and the sketches for those can be found in figure 6. In the first idea, some squares with numbers on them would appear on the screen in random locations and the player had to touch them starting from the smallest number in ascending order as fast as possible. The difficulty could be determined from the amount of numbers and if they followed a pattern for example numbers from 1 to 10, starting from 2 and always incrementing by 2, odd and even numbers or totally random. The score would be calculated based on reaction time and input accuracy. The game would feature a cognitive component as the player has to think about the order of the numbers. As there are multiple choices present at the same time, Hick's law can be conveniently utilized. We liked this idea a lot but deemed it too simple and quite boring.

In the next game, colored shapes fall from the top of the screen to the bottom and the player has to choose a color and a shape that correspond to the shape the player is going to touch. If the color and shape are correct then the shape disappears and the player is awarded points based on reaction time and input accuracy. More shapes fall down and at higher speed as the game goes on and the player loses when a certain amount of shapes are missed. This was a good idea but the gameplay requires lots of inputs making it unnecessarily complex and thus not fun.

We also thought about a game where circles would appear on the screen and disappear after a little while. The circles would have layers which would disappear gradually thus making the circle smaller and harder to touch and also granting less points. This game resembled a certain rhythm game too much so we scrapped it.

We got the last idea at the meeting when discussing and mixing the designs. We aimed to make the gameplay fun and simple. As elderly people commonly play slot machines at grocery stores, we thought about why they appeal to elderlies so much except for the gambling aspect. We took some elements from those games that we thought were fun and added a reaction component. There are 5 lanes in the game and different colored shapes fall from the top of the screen at the same level and speed. The player then has to touch only a certain shape that could be seen somewhere on the screen clearly and might change. We also thought about adding a swipe function so that if there are for example 5 correct shapes on the same row, they could be swiped for extra points. Again the player would lose after a certain amount of shapes are missed.

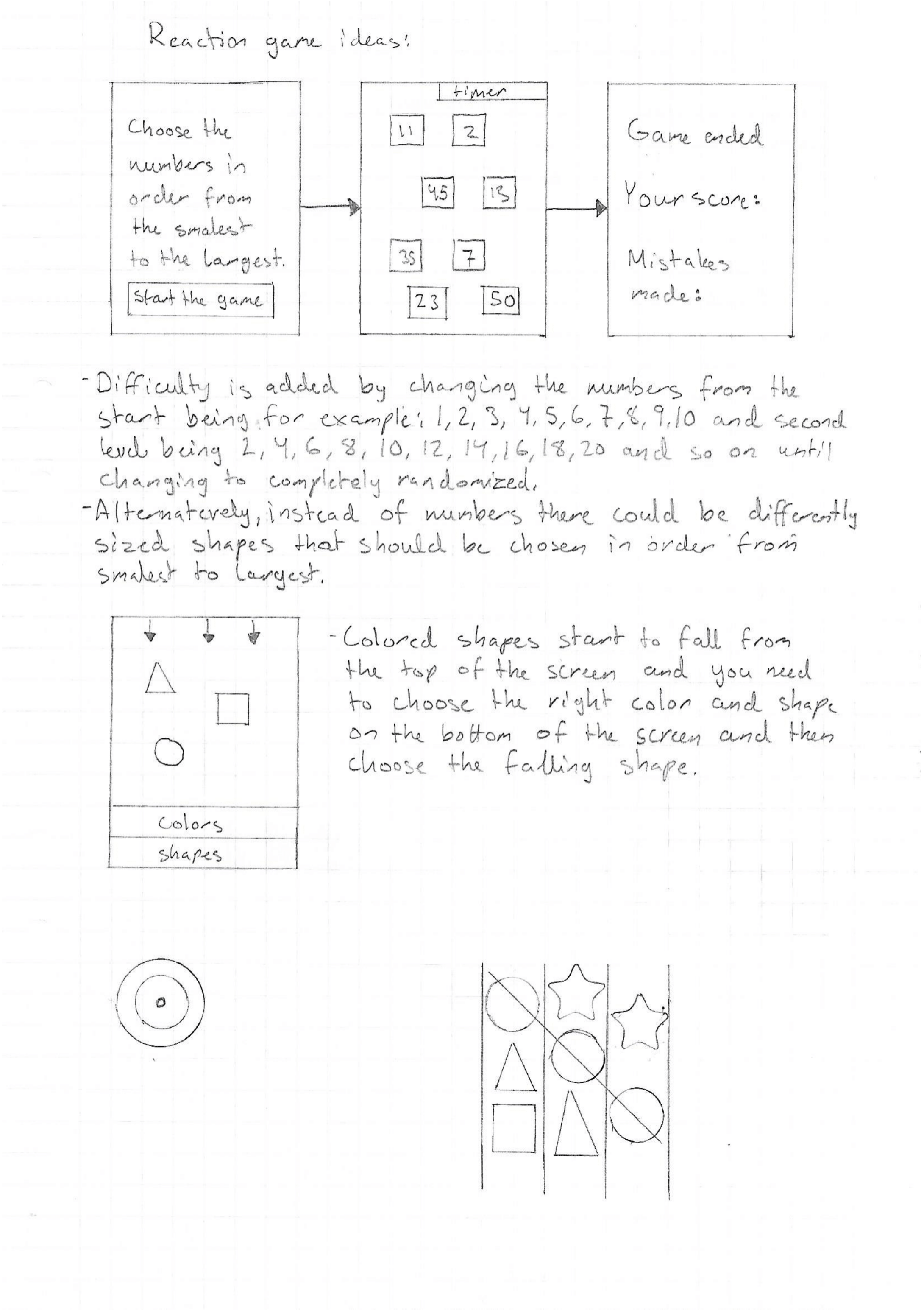

Figure 6. Reaction game sketches.

3.2. Final Designs and Implementation

We chose the trail memorizing game as our memory game because the gameplay seemed fun and also it presented a convenient way to measure cognitive performance. We chose the slot machine inspired reaction game as the reaction game.

We started the implementation on the 5th of December, and decided to make the memory game first. Samuli made a quick prototype of the path generating grid for the next meeting where we started planning the implementation. We figured out the relevant components which the game would consist of, and assigned them to each team member. The main components can be found in figure 7.

TODO:

Memory Game (Now)

OnClick/TouchListener for the whole screen: STATUS: NOT DONE

GameObject class: STATUS: NOT DONE

Main menu: STATUS: NOT DONE

Retrypage: STATUS: NOT DONE

Path algorithm: STATUS: NOT DONE

Game logic: STATUS: NOT DONE

Measurements/Score: STATUS: NOT DONE

Making everything pretty: STATUS: NOT DONE

DEADLINE: 15.12.2019

Figure 7. Memory game components.

We agreed that Jenni would be responsible for implementing the main menu, the retry page and graphics. Samuli would take care of implementing the path algorithm, score and measurements calculations, and the TouchListener for the whole screen. Lastly, Niklas would implement the game logic and GameObject class. We set the initial deadline to 15th of December. Such a short deadline was meant to kickstart the project and to prevent procrastinating.

3.2.1. Memory Game

As none of us had any experience with Java, the progression was quite slow and clunky at first, but since we had previous programming experience, we learned the syntax and behavior of Java quite quickly. We knew some components had to be done before others and even then the development of the game took longer than we expected.

Our development journey began with Niklas making our github repository. After this Jenni made the main menu page for our application. Next, Samuli made the TouchListener for the memory game. In due time Niklas was developing the GameObject class and the virtual coordinate system which is used to form the grid with the right scale based on the mobile device's resolution. After the GameObject class was ready, Samuli began developing the path algorithm which is used to generate the path which the player has to remember. During this time Jenni put her development time into making the retry and exit page. Now that the path algorithm was ready and we could see some kind of core gameplay mechanics on the screen, we started thinking about how to make the gameplay experience nicer and we came to the conclusion that a fade animation for the game objects would be nice, so Niklas made a color class with support for fading and finished the core game logic. After our game logic was working as intended, Samuli implemented the score and measurement system which is used to assess cognitive performance. After this all the major components had been implemented and all that was left some fine tuning, bug fixes and graphics.

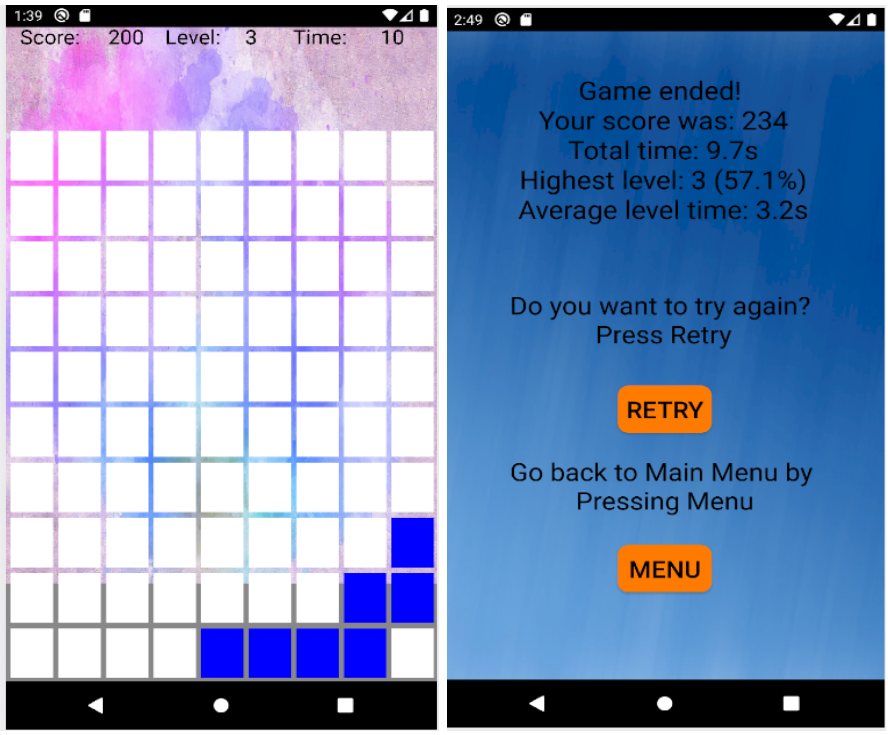

Figure 8. Memory game gameplay.

In figure 8 there are 2 screenshots from the finished product. On the left the player has started level 3 and the path is shown one square at a time. The squares fade from white into blue as they appear and after all whole path has been shown, all squares fade back to white except the bottom middle one which is always the starting point. The player then has to swipe to the direction they want to go, revealing the next square by fading it into blue or if the direction was wrong then the whole path is shown in red and the game ends. If the player manages to reveal the whole path, it turns green, the player is awarded points based on time and the next level begins. On the right is the retry page where the results and performance is displayed, the player can choose to play again or go back to the main menu.

3.2.2. Reaction Game

Game2 (SOON)

OnClick/TouchListener for the whole screen: STATUS: COPY FROM MEMORY GAME

GameObject class: STATUS: NOT DONE

Main menu: STATUS: ADD BUTTON TO MENU

Retrypage: STATUS: NOT DONE

Moving game objects: STATUS: NOT DONE

Spawning / removing objects out of screen: STATUS: NOT DONE

Game core logic: STATUS: NOT DONE

Measurements/Score: STATUS: NOT DONE

Making everything pretty: STATUS: NOT DONE

DEADLINE: 10.2.2020

Figure 9. Reaction game components.

We started by figuring out the major components for the reaction game, which turned out to have quite a bit of similarities with the memory game and because of that we were able to reuse some components. Since at this point we had better understanding of Java, the development process was a lot quicker and smoother compared to the memory game.

The reaction game development started by Jenni adding a button for the game in the main menu and handled the button and page scripting overall. After this Niklas made the GameObject class for the reaction game and constructed the base for the game. Meanwhile Samuli made nice looking sprites for the game objects and also figured out the relevant measurements and statistics that we would be collecting as well as implemented the means to get them.

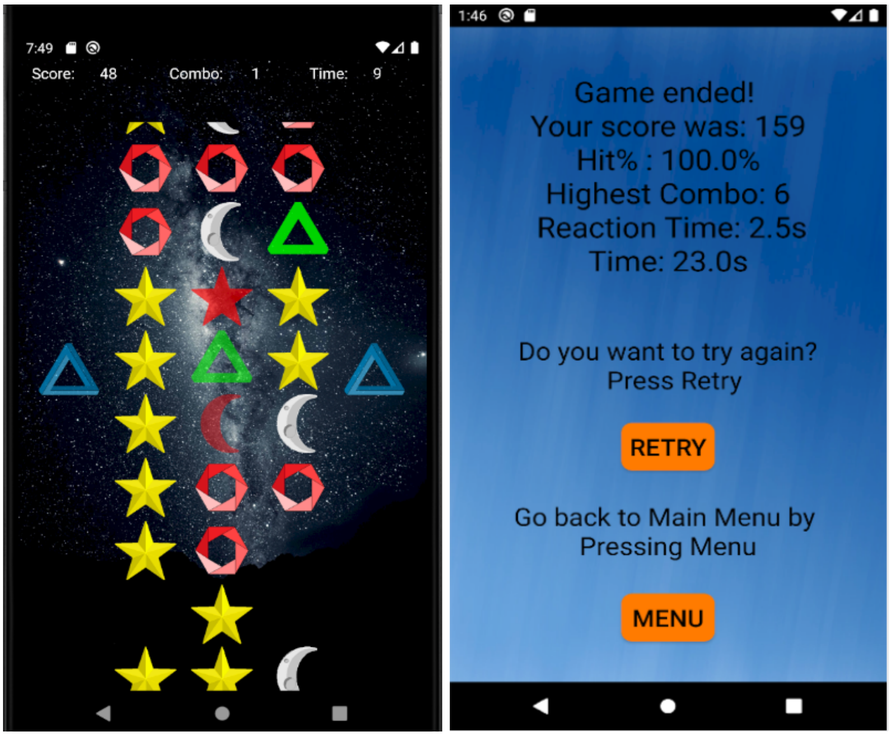

Figure 10. Reaction game gameplay.

The finished reaction game is presented in figure 10. On the left screenshot the game has just started and the correct shape that needs to be touched is a triangle and it can be seen on the side lanes. It is a static shape indicating the shape that needs to be touched. The correct shapes start blinking two seconds before they change to a new one. Two fading triangles can be seen as green as the shapes turn green and fade away when they are touched if they are of the correct shape, otherwise they turn red and fade away if they were wrong, like the moon and star in the figure. The game gets slightly faster as time goes on, making it harder to keep up. The game keeps going until 10 shapes have been missed or the score is less than -25. For each correct shape the player is awarded 10 points + the combo amount (the number of correct shapes in a row without missing any). Again on the right screenshot the results and performance is displayed and the player can choose to play again or go back to the main menu.

3.3. Study Design

In this study we are trying to find out how cognitive performance among different age groups can be measured with a smartphone game. We have made two different games, one for measuring reaction time and another for measuring memory. The reaction time game will also tell us about the participants input accuracy.

3.3.1. Test Methodology

Our experiment will be done as in-the-wild test since playing the game does not require lab environment and since it will be most convenient for our test participants. We will be gathering quantitative data, which will be recorded separately from each of the rounds that the participants will be playing the game.

The game will be played on the researcher's smartphones to avoid needing to install the application to the participants' personal smartphones. Since the test environment is not same for all participants, some requirements for the space, where the test will be conducted, were discussed. Two requirements that needs to be filled are that the space should be peaceful, and that the participant should be doing the test while seated. A question was raised about whether we should make all the participants play the game holding the phone in a certain way, for example holding the phone so that you can play with both thumbs. After some discussion we ended up agreeing that the best option is to let the participants play the way they want, so that it is most comfortable for them and so that the test results are not showing some changes because the player was not used to holding the smartphone in a certain way.

The results of each individual test round for both games will be written down on the test sheet by us which can be found in figure 11.

3.3.2. Test Subjects

We decided on having two different age groups of participants. In the first group we will be having testees that are age 50 to 65 and in the second group we will be having testees that are age 20 to 25. Number of participants was decided to be 6 per group, since finding older participants that fit in the age range seemed to be difficult aside from the people that we know (friends, parents, relatives, and etc.).

Since the participants will be people we personally know, we will be contacting them via our personal contacts with them. The locations, where the test will be conducted, will be decided together with the participants. The place will be chosen so that it meets our requirements and is most convenient for the participants.

For each participant we will be giving a specific participant number so that we can take a look at the individual scores without having to use names to keep track of the participants. This will be helping to keep the test results organized and it will ensure anonymity for the participants.

3.3.3. Test Procedure

In this subsection we will be going through the test procedure that we will be following as we conduct the test. Every step of the process will be listed here.

1. Both the researcher and the participant will arrive in the test location

2. The participant will take a seat and the test procedure will be explained to them.

3. The researcher will ask the participants to provide some information which includes their age, dominant hand, the possible medical conditions that could affect the results and if they own a smartphone. This information will be recorded in the result sheet with the participant number.

4. The researcher will explain how the games are played, what is the goal in each game and what to do after the game ends. After the verbal explanation the researcher will demo briefly how both the games are played.
5. The phone is handed to the participant and the game will be on the menu page.
6. The participant will play the memory game once as a practice round so that they are comfortable with how the game works. This round will not be included in the test results.
7. After the practice round, the participant will go to the menu page and start the first real test round.
8. After completing the round, they will hand the phone to the researcher who will record the results of the round in paper on the following manner.
   - The result sheet will include participant number, age, related medical conditions and dominant hand of the participant. They will be also asked if they own smartphone or not. Then there will be slots where to mark results for each round of the games. Figure 11 shows the result sheet.
9. The phone is handed back to the participant and the second and third rounds are done same way as the first round (parts 6 and 7)
10. After the third round is over and the results are recorded, the reaction game section of the test is started. It will be conducted in same manner as the memory game (parts 6 to 9)
11. After the practice round and three test rounds are played and all the results are recorded the testing section is over.
12. The participants can tell how they felt about the games, they will be thanked for the participation and the test is fully completed.

3.3.4. Test Outcomes

In the memory game, the measured types of data are score, total gameplay time, highest level reached before a mistake and average level time. The score is made by giving +10 points for each correct choice made and completing the level gives bonus points which depends on the gameplay time. The level reached includes how many steps the testee got right in the current level before the mistake was made and the game ended. The average level time is calculated by taking the mean of the total time which is measured in seconds. The result is shown as the number of the level reached and the correct steps before mistake as a percentage. When the game ends the end screen will appear and the different results are shown and the results are recorded by the researcher after each round.

In the reaction game, the measured types of data are score, reaction time, accuracy percentage, highest combo and gameplay time. The score is made by giving +10 points for each correct shape chosen, combo amount (choosing more than one correct shape in a row without missing any) is added to the 10 points for each correct shape and 5 points is lost when wrong shape is chosen or the shape is missed outside of the threshold after the shape has changed. Reaction time is measured by taking the time in which first shape is chosen after the target shape has changed. Accuracy percentage shows how many of all the choices made were correct. Highest combo is the highest number of correct choices in a row before a wrong shape is chosen or a correct shape is missed and the combo counter is cleared. The game ends when 10 correct shapes are missed or negative score of 25 is reached. On the end screen the score, accuracy percentage, highest combo, reaction time and the gameplay time are shown and results are recorded by the researcher.

All these results are used to compare if there is significant difference in the results between the two age groups.

3.4. Implementation Testing and Piloting

After some final modifications we declared our implementation ready and began our pilot test runs. We each took turns to go through the test procedure of doing the actual test as described in subsection 3.3.3. Then again, since we know how to play the game the demo played by the researcher and the test round played by the testee were skipped and only the three real test rounds were played. We recorded all the test results of our pilot test and we will discuss the results briefly later in this chapter.

On the very first round of memory game, played by one of the researchers, we noticed two issues. First one was the amount of levels which we decided to increase, since the game was too easy to pass. From the former 6 we increased the levels to 10 which proved to be a sufficient amount of levels since none of us completed the final 10th level on the test runs. The second issue we noticed was that when the final level was reached the percentage showing how many steps were taken correctly was not correct, so we also fixed that. After these fixes were made, we continued the test by ignoring the first round of the researcher's and letting them play the planned three real test rounds with the fixed version of the game. No other issues where found, and the test results were recorded.

Of our pilot run results we decided to show the results by showing averages of both our individual scores and our combined scores. As for the real participants, our scores will as well be under a participant number. And the results are as presented here.

Attributes				
Testee	Age	Dominant Hand	Any Conditions	Owns a Smartphone
Y1	21	Right	No	Yes
Y2	22	Right	No	Yes
Y3	22	Left	No	Yes

Table 1. Different attributes of the researchers.

Memory Game Averages				
Testee	Score	Total Time	Highest Level	Level Time
Y1	648	37.9s	6 (98.1%)	5.6s
Y2	837	47.4s	8 (54.6%)	5.6s
Y3	851	23.9s	8 (16.1%)	3.3s

Table 2. The average results the researchers got in the memory game.

Reaction Game Average					
Testee	Score	Hit%	Highest Combo	Reaction Time	Time
Y1	2518	95.4%	32	0.9s	78.1s
Y2	14436	92.6%	138	0.7s	139.2s
Y3	16243	94.9%	118	0.8s	151.2s

Table 3. The average results the researchers got in the reaction game.

Researcher Group's Memory Game Average			
Score	Total Time	Highest Level	Average level time
779	36.4s	7 (89.6%)	4.8s

Table 4. The average of the researchers' results in the memory game.

Researcher Group's Reaction Game Averages				
Score	Hit%	Highest Combo	Reaction time	Time
11066	94.3%	96	0.8s	122.8s

Table 5. The average of the researchers' results in the reaction game.

When comparing the individual results, we can already see some quite clear differences. This indicates that differences will also be found in the actual study, when just within us 3 we can clearly mark differences. However, the most interesting subject for our research is to see if a clear difference can be found between the different age groups and then analyzing that difference.

Participant number	
Age	
Dominant hand	
Conditions, which may affect the results	
Owns smartphone	

Results:

	Memory 1	Memory 2	Memory 3
Score			
Total time			
Highest level			
Average level time			
	Reaction 1	Reaction 2	Reaction 3
Score			
Hit%			
Highest combo			
Reaction time			
Time			

Figure 11. Test result sheet.

4. EVALUATION

4.1. Testing the Application

We tested the application on six people from each age group. Here is how the procedures went for the participants who tested it remotely and for those who tested in person. For the testees who tested the games in person the procedure went as explained in section 3.3.3. For remote testees the test procedure went as explained below.

1. At first the researcher made a phone call or a video call to the testee and sent the application and the answer sheet to the testee. We also provided pictures of certain steps in case there was a need for them.
2. The testee downloaded the application.
3. The researcher explained in general what is tested and how its tested.
4. The testee was asked to fill in their information on the answer sheet.
5. The researcher explained the memory game.
6. The testee played the memory game practice round(s).
7. The testee played the first testing round of the memory game.
8. The testee recorded the results of the first round in the results sheet.
9. Parts 7 and 8 repeated for the two other testing rounds.
10. Parts 5 to 9 repeated for the reaction game.
11. After the games were played the testee send the result sheet to the researcher.
12. The researcher asked testee to give some feedback on the game and the test experience.
13. The researcher thanked the testee for the participation in the test and the test was over.

4.2. Limitations

We wanted to have more testees but unfortunately, because of the ongoing coronavirus pandemic, we had to settle for a total of 12 people consisting of our friends and family. Also, because of the social distancing recommendations, we conducted some of the tests remotely by writing instructions on how to install the game on the smartphone, how to play the game and how the test procedure is done.

Because of the remote testing procedure and confusing controls on the games, we decided to give some testees more test rounds before the actual tests so they could learn to play the game properly and get results that better reflect their abilities. Also, because of not being able to conduct the tests in person made it harder to correct their mistakes and guide them.

Since in almost all cases there were multiple testees present at the same time, the testees disturbed each other on some level, which might have affected the results.

4.3. User Feedback

We received valuable feedback from the testees which can help improve the gameplay and the quality of the data in the future. Here we have collected some common opinions and thoughts about each game.

First of all, pretty much every testee unanimously agreed that they were confused about how the memory game was supposed to be played at first. For example many testees tried to draw the path by holding their finger on the screen and dragging it through the path which does make sense and seems to be more intuitive. The testees also perceived the memory game as quite boring which made it harder for them to focus on the game or take it seriously so if you happened to get distracted, the game would be easily lost which leads to worse results along with not taking the game seriously. The reaction game was received much better and most testees genuinely thought it was fun to play. Although there was some confusion about playing the game. Losing the game was quite unclear as there was no counter or anything to show how many shapes were missed so some testees ignored the shapes that passed by and were unaware of their importance and because of this they were surprised when the game suddenly ended.

Finally we decided to include some direct comments and thoughts from the testees which are translated below.

Testee Y5: "*In the reaction game it is annoying to try to touch the shapes that are at the bottom right after the correct shape changes. Also, the timer that determines if the shape is alive is inconsistent.*"

Testee X1: "*Fun game after learning how to play it. Both games are simple enough. Wanted to play the game more. Maybe a tablet version would be nice to play since the game objects would be bigger. The testee noticed their mistake in the approach of the reaction game.*"

Testee X2: "*In the beginning it felt a bit overwhelming since they needed to download the games and the other non-game-related things. Would have liked doing the test better with the researcher present. But considering the situation, the test went surprisingly well. The playing itself was nice after getting to know how you are supposed to play the game*."

Both testees X1 and X2 noted that it was too easy to accidentally touch the phone buttons on the bottom of the screen and end up at the home screen.

Testee X5: "*Reaction game was more fun, though there was a little bit of confusion because of the two shapes on the side lines that indicate the correct shape. The testee thought that you can only press the shape when it is between the mentioned shapes. It was also easy to get distracted in the memory game.*"

Testee X6: "*The games were easy to understand. Memory game felt too long, and because of its nature it was easy to get distracted if there were two testees in the same room at the same time. Reaction game was a lot more fun to play. Memory game controls could be changed since it caused errors when you pressed the screen instead* *of swiping. For example the game could be changed to ignore the input when only pressing the screen.*"

Both testees X5 and X6 agreed that the memory game would be better for assessing cognitive impairment in elderlies but the reaction game might be too fast paced for them.

4.4. Evaluation Results

The testees with the Y prefix represent the younger age group, and the testees with the X prefix represent the older age group.

Attributes				
Testee	Age	Dominant Hand	Any Conditions	Owns a Smartphone
Y1	21	Right	No	Yes
Y2	22	Right	No	Yes
Y3	22	Left	No	Yes
Y4	22	Right	No	Yes
Y5	22	Right	No	Yes
Y6	22	Right	No	Yes
X1	62	Right	No	Yes
X2	58	Right	No	Yes
X3	51	Right	No	Yes
X4	57	Right	No	Yes
X5	61	Left	No	Yes
X6	61	Right	No	Yes

Table 6. Different attributes of the testees.

Memory Game Averages				
Testee	Score	Total Time	Highest Level	Level Time
Y1	648	37.9s	6 (98.1%)	5.6s
Y2	837	47.4s	8 (54.6%)	5.6s
Y3	851	23.9s	8 (16.1%)	3.3s
Y4	935	35.7s	8 (85.0%)	4.3s
Y5	995	38.1s	9 (23.4%)	4.3s
Y6	745	24.2s	7 (42.4%)	3.4s
X1	495	57.6s	6 (75.9%)	9.3s
X2	310	33.1s	4 (85.9%)	7.3s
X3	539	29.2s	6 (34.5%)	5s
X4	264	15.3s	3 (97.0%)	4.6s
X5	455	23.8s	6 (0.0%)	19.9s
X6	300	36.6s	5 (1.9%)	8.0s

Table 7. The average results the testees got in the memory game.

Reaction Game Averages					
Testee	Score	Hit%	Highest Combo	Reaction Time	Time
Y1	2518	95.4%	32	0.9s	78.1s
Y2	14436	92.6%	138	0.7s	139.2s
Y3	16243	94.9%	118	0.8s	151.2s
Y4	4340	95.4%	51	1.0s	100.7s
Y5	4111	93.0%	47	0.9s	111.3s
Y6	10632	94.2%	105.7	0.8s	131.4s
X1	224	100%	8	1.1s	24.3s
X2	1685	90.1%	34	1.9s	52.1s
X3	736	95.0%	13	1.2s	46.8s
X4	1134	98.0%	19	1.1s	51.9s
X5	1288	98.6%	23.3	1.1s	55.3s
X6	5181	94.5%	56	1.2s	108.1s

Table 8. The average results the testees got in the reaction game.

The researchers' results are part of the younger test group, testees Y1, Y2 and Y3, and they can also be found in the subsection 3.4.

4.4.1. Memory Game Usability

The main concern for the memory game was the controls, as some testees pressed the cell they wanted to move in instead of swiping, which registered the movement direction unpredictably and ended up causing a movement in an unintended direction and ending the game.

4.4.2. Reaction Game Usability

In the reaction game there was no counter for the missed shapes, so there was no indication when the game was going to end. This resulted in the testees not understanding the importance of not letting the correct shapes pass. The indicators for the correct shape also caused confusion because the testees sometimes mistook them for actual game objects and tried to touch them.

4.5. Analysis

We decided to use Mann-Whitney U test to see how much the results differ between the two age groups. We looked into other methods such as Wilcoxon-signed rank test and Student's t-test, but since we cannot assume a specific distribution and the results are independent, Mann-Whitney U test is the most suitable method for our needs. If the ρ-value is less than 0.05, it suggests that the samples are from different populations. [39].

4.5.1. Memory Game

Memory	Score	Total Time	Highest Level	Average level time
Younger Group Average	859.6	33.4s	8 (26.0%)	4.3s
Older Group Average	394	34.6s	5 (48.9%)	6.8s
U	14	159.5	28	46.5
z-score	5.18208	0.06328	4.22375	3.76797
ρ-value	< 0.00001	0.95216	< 0.00001	0.00016

Table 9. The average results the age groups got in the memory game.

In the memory game the ρ-value is significant for the score and the highest level, so we can say that there is a statistically significant difference between the groups, which was expected. The values for score and highest level go hand in hand since reaching a high level results in a high score. The average level time ρ-value is also clearly significant but a little less than the ρ-value for score and the highest level. The ρ-value for total time however is far from significant. Surprisingly the average total time for both groups were almost equal (33.4s & 34.6s).

4.5.2. Reaction Game

Reaction	Score	Hit%	Highest Combo	Reaction time	Time
Younger Group Average	10135	94.6%	92	0.8s	122s
Older Group Average	1658	96.2%	25	1.2s	55.7s
U	20	68	28.5	11	12
z-score	4.47686	-2.95821	4.20793	-4.76161	4.72997
ρ-value	< 0.00001	0.00308	< 0.00001	< 0.00001	< 0.00001

Table 10. The average results the age groups got in the reaction game.

In the reaction game all of the ρ-values are significant. We are mostly interested about the reaction time and hit percentage ρ-values. In reaction time there was an expected difference. In hit percentage the difference was not so big mainly because the older group was more focused on hitting the right shape rather than catching all of them, which resulted in errors and games not lasting long enough for the game to get fast enough to cause actual accuracy mistakes.

5. DISCUSSION

As a result of the applications complexity there was a big difference in the results between the two age groups as the older group is not as used to playing games or using a smart phone as the younger group. Another thing that affected the results was that we were not able to properly demonstrate how the games should be played because of the pandemic. We noticed that the scores of older people increased significantly if they played more after the test session, from which we can conclude that the younger group grasped how the games should be played a lot faster.

The number of times the games were played before the actual testing should be increased to make sure that the testees know how to play the games properly and provide more accurate data. Especially for the older age group as they are not as used to using smart phones or playing games as the younger group.

During the tests we noticed many different styles of playing, for example some testees played against a table, used only 1 finger or did not use swiping at all. Some testees also switched their styles between tests to see if a different style worked better which can be seen as a sign that the player tries to improve their results.

Afterwards we realized that the testees should have filmed or streamed themselves playing the game to make sure that they are playing correctly and that we should have recorded a video that shows how to play the games instead of writing the instructions as watching a video on the gameplay would give a much clearer concept about how the games should be played.

5.1. Memory Game

The memory game lacked engaging gameplay and was perceived as boring or slow. Because of that the game was not very compelling for the testees, which resulted in the users getting distracted and the scores not being as good as they could be. Another impacting factor in the memory game results was that some testees tried to press in the direction instead of swiping, which registered the movement direction unpredictably and ended up causing a movement in an unintended direction and ending the game.

The memory game needs more intuitive controls or we need to make an in-game tutorial which clearly demonstrates the gameplay and controls.

5.2. Reaction Game

Also, more emphasis should be on assessing the reaction time as at the moment, having good reaction time does not give any score so players might not care about having a good reaction time. On the other hand the game encourages building big combos and having good input accuracy. Simply put, the game rewards consistency instead of the reaction time. The reaction game also needs a clear in-game tutorial as well.

Some testees from the older age group continued playing the reaction game after the testing was done and got significantly better results. Some of the scores were as much as 10 times higher than in the testing phase.

6. CONCLUSION

This thesis describes the implementation and evaluation of two serious games for motor and cognitive assessment, one is focused on assessing the performance of memory, while the other is focused on assessing reaction time and input accuracy.

First, we research that there is a demand for applications that assess health which became our motivation. Then, we study how to measure different motor and cognitive properties, and diseases that could benefit from serious games. We also scratch the surface of Android development and make our first demo applications. We brainstorm ideas for the games, design and implement our memory and reaction game, devise the evaluation plan, and test our implementation ourselves. Finally, we test the application with two different age groups and analyze and discuss the results we got using Mann-Whitney U test.

6.1. Future Work

Our priority for now would be to make the games less confusing so that the participants can learn to play the games faster and require less practice rounds.

In the future, we would like to implement some changes to the game based on the feedback that we received. Then, find out ways to make the game collect more accurate data more reliably and verify that the results are correct.

We would also change the test procedure a bit, for example more effort should be placed on minimizing distractions, especially with the memory game since it requires the players full attention and we should motivate the testees more to get them to play the games more seriously. Finally, we need to make sure that before testing, the participant fully understands how to play the games to get the most accurate results.

After we have revisited and improved the game and the test procedure, we would like get more testees and gather more data, since at the current state our results are not as accurate as they could be, and the amount of testees we had was quite low. However, we are pleased with the results we got so far, and we have a solid foundation for continuing the work.

7. CONTRIBUTION

In the background research and related work, after we knew what to write, we equally split the workload by assigning each member a set of topics to write about. Niklas was in charge of writing about Reaction Time, Hick's Law, Parkinson's Disease, Multiple Sclerosis and he made the demo 2. Samuli wrote the Introduction and the following subsections: Fitts' Law, Methods for measuring memory, Mild Cognitive Impairment and did the demo 3. Jenni wrote the introduction for the Background research and related work and the subsections about Serious Games, Input Accuracy, Cerebral Palsy, Older Adults and Video Games and made the demo 1. The remaining parts were done together in our meetings.

During the design and implementation phase we first decided which memory game idea we would implement. We then thought which parts could be developed simultaneously and assigned those tasks to each researcher. We repeated the same steps for the reaction game. The writing part was split according to the amount of time used with the implementation. Samuli was in change of writing the subsections about Design Ideas, Memory Game Ideas and Reaction Game Ideas. Jenni focused on the Study design and all its subsections. Niklas and Samuli wrote the Final Designs and Implementation section and its subsections Memory Game and Reaction Game. All of us worked on the Implementation testing and piloting section. The different development tasks we assigned to each researcher can be found in the Final Designs and Implementation section 3.2.

During the evaluation phase we agreed to reach out to our friends and families to get testees. Samuli conducted the tests with 5 and Jenni and Niklas with 2 testees. After the testing was done, we organized meetings frequently, and wrote the sections and subsections in Evaluation, Discussion and Conclusion chapters together.

Time usage	
Vaara	223h
Peltomaa	222h
Holappa	221h

Table 11. The number of hours each researcher used for this project.

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